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ABSTRACT

This study examined the role played by particular intellectual and physical environments on concept formation, focusing on conceptions concerning heat in a group of non-western subjects living in the interior of southern Africa (N. Sotho and Tswana peoples). In addition, these conceptions were examined in three contexts of the subjects' cultural knowledge concerning heat, the prevailing paradigms concerning heat found in early/contemporary scientific theories, and the physical environment in which subjects live. Subjects (N=20) included school-age children and schooled/non-schooled adults. Previous research indicates that European languages such as English tend to reinforce notions of heat as "caloric" because of the historical antecedents of the concept of heat which remain embedded in the language. However, analysis of Interviews-About-Instances and Piagetian clinical interviews suggests that the N. Sotho and Setswana languages appear to involve connotative meanings of heat which are influenced in some way by a powerful metaphor in the Sotho cultural beliefs, and which have a predisposition toward prekinetic views of heat. These results suggests that the Sotho people may be at a relative advantage in learning about heat energy when compared to their western counterparts because their existing knowledge of heat is, in some sense, close to a kinetic view. (JN)

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THE INFLUENCE OF INTELLECTUAL ENVIRONMENT ON CONCEPTIONS OF HEAT

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Summary

The focus of this exploratory study is on the role played by cultural metaphors in the conception of the physical phenomenon of heat in the N.Sotho and Tswana peoples.

It has been found by other researchers that Western children often have concepts of heat which can be described as 'caloric'. These concepts persist despite formal instruction which makes use of the kinetic model of heat in which heat is seen as a form of energy. This research tends to suggest that the caloric conception of heat is more prevalent in Western subjects than in those involved in this study. A tentative conclusion is that European languages such as English tend to reinforce notions of heat as a caloric because of the historical antecedents of the concept of heat which remain embedded in the language. On the other hand, the N. Sotho and Setswana languages appear to involve connotative meanings of heat which are influenced in some way by a powerful metaphor in the Sotho cultural beliefs, and which have a predisposition towards prekinetic views of heat.

The term heat is frequently misused by layman and scientist alike. (Harris, 1981, and McGlashan, 1966). In a recent advertisement, for an evaporative air conditioner, found in a local newspaper it was claimed that as the water droplets evaporate, "they consume the heat. molecules in the atmosphere". The drawing in Figure 1 accompanied the advertisement.

Figure 1 About Here

The message of this advertisement is that heat is matter consisting of molecules, similar to water molecules. This view of heat is generally termed 'the caloric view' and is consistent with that prevalent in the seventeenth and eighteenth centuries. Harris (1981) claims that many students' conceptions of heat today are , on the whole, not very different from those of Lavoisier (1789), that is, they think calorically. He suggests that the subject of heat is one of the most confused in science and that the source of confusion centres around the semantic use of words 'heat', 'heat flow', 'heat capacity', and so on. While the word 'caloric' has all but been eliminated it appears as if the concept of heat as caloric persists even though the current scientific view of heat as kinetic energy is officially taught in schools.

Researchers in the West have observed caloric conceptions of heat in children, for example in the U.S.A. (Albert, 1978), Canada (Erickson, 1975, 1979, 1980), France (Tiberghien, 1980) and in England (Shayer and Wylam, 1981).

There is no known data regarding the presence of caloric conceptions in non-Westerners. It is, however, well documented that there is a prevalent metaphor involving heat amongst many African peoples, and in particular, the Sotho people of Southern Africa (Schapera, 1979; Hammond-Tooke, 1981; Verryn, 1981). This metaphor or cultural belief is a dominant aspect of the intellectual environment of the Sotho people, but is almost entirely absent from the intellectual environment of Westerners. This is possibly reflected in the Sotho languages in which different words are used for the meanings of heat — (objective: '<u>bollo</u>' - the object is hot; and subjective: '<u>fisa</u>' - the person feels hot).

The focus of this study is on the role played by particular intellectual and physical environments on concept formation. In other words, is the presence of particular conceptions of heat in Westerners and non-Westerners a function of their intellectual environments?

General Background

In his discussion of issues for cognitive science, Norman (1981) suggests that a consideration of both the 'internal' and 'external' aspects of a functioning cognitive system should be investigated. The 'internal' aspects, which are not considered in this study, concern aspects of information processing. The 'external' aspects concern the influence of the intellectual (i.e., cultural knowledge and beliefs) and physical environment on cognition. Norman (1981:278) describes cultural knowledge as a "subset of general knowledge that is passed on from generation to generation" by society. The physical environment concerns the facts and events of the real world which provide a constant input, interacting with the cultural knowledge. Indeed Norman (1981:279) suggests that the way in which individuals perceive their physical environment is affected by or even altered by their cultural knowledge. Similarly, Lakoff and Johnson (1981:146) suggest that "the social reality defined by a culture affects its conception of physical reality."

Petrie (1976) provides a model (Figure 2) which is slightly adapted to form the theoretical basis of this study. Petrie (1976) describes individuals as having 'representational schemes' which we refer to as 'conceptions'. In this model, conceptions are seen as existing in a dynamic interaction between the cultural and social beliefs of the society; the prevailing paradigms or theories of the society; and the input from the facts and events of the physical

world. This interpretationalist view of concepts espoused by Petrie (1976) is similar to Toulmin's (1972) idea of conceptual ecology. Both see thought in a relativistic perspective and interpret concept formation according to the varied mental sets of individuals which are a function of their intellectual and physical environments.

Figure 2 About Here

The term 'conception' is used here to mean the structural aspect of knowledge and can be more loosely described as an idea. A 'conception' is understood as involving both propositional and procedural knowledge (Shavelson, 1974). There may be scientific conceptions which conform to the prevailing orthodox scientific paradigm and there may be alternative conceptions. These are viable ideas which provide a certain amount of explanatory and predictive power to the individual concerned, but which differ from the scientific conceptions (see Hewson, 1982 for a more detailed description of alternative conceptions, also Driver and Easley, 1978).

This study seeks to describe the conceptions concerning heat in a group of non-Western subjects. It also seeks to understand the conceptions in the three contexts of the subjects' cultural knowledge concerning heat, the prevailing paradigms concerning heat as found in early and contemporary scientific theories, and the physical environment in which the subjects live. Each of these contexts will be

described.

The Physical Environment.

The subjects in this study live in the hot, arid area in the interior of Southern Africa. The land has few natural agricultural resources and an adequate supply of water is a major concern of the people.

Most of the subjects live relatively simply. Electricity is seldom available and cooking is frequently done with coal or wood stoves or on the open fire.

Cultural Knowledge Concerning Heat.

The harsh environment described above appears to have given rise to a powerful metaphor concerning heat which pervades many aspects of life. Anthropologists (Schapera 1979, Hammond-Tooke, 1981 and Verryn, 1981) document that the Sotho group of peoples living in this area believe that 'coolness is good' (implying health and social harmony) and the converse 'hot is bad' (implying sickness and social disharmony). These ideas can be termed metaphors, and, as Lakoff and Johnson (1981) point out, all metaphors are grounded in experience. In this case the metaphor is grounded in the hardship caused by a hot, dry environment. We interpret this as an instance in which the individual's conceptions in the form of metaphors may indeed be

influenced by both environmental factors and cultural beliefs.

The metaphor involving heat is used in many instances in everyday life, such as birth, pregnancy, menstruation, death, especially death by lightning, sickness, and a variety of situations involving negative feelings, for example, anger, impatience, anxiety. A person who is in one of these situations is said to be 'hot'. Such a person's blood is particularly susceptible to heat, in which condition it is said to be 'agitated' or 'fighting with itself'. A person who is 'hot' is potentially dangerous to others, especially babies, men, and livestock. Cooling is a basic concern in Sotho medicine. Cooling treatments involve the use of certain plants, animals, water, and ash.

Schapera (1979), Hammond-Tooke (1981) and Verryn (1981) document the heat metaphor of predominantly rural people. It is of interest to establish whether this cultural metaphor also pertains in people who are semi-urban, who have become somewhat acculturated to the Western way of life and thought, and who have had some experience of Western schools.

Prevailing Paradigms Concerning Physical Heat.

The formal Western scientific understanding of heat has involved a paradigm shift. In the sixteenth and seventeenth centuries scientists such as Lavoisier (1789) believed in the caloric view of heat, in which heat was believed to be a kind of fluid called 'caloric' which flowed into or out of bodies when they became hot or cold respectively (Gordon et al., 1968; Zemansky, 1957).

However, in the nineteenth century the kinetic view of heat became prevalent. According to this latter view, heat is one form of energy in transit. In other words, it is energy which is transmitted from an object at a high temperature to another at a low temperature (Brink and Jones, 1977; Zemansky, 1957). The kinetic theory of heat is taught in schools at standard 8 (Grade 10) level. The subjects in this study have not been formally taught this view, but may have had some instruction involving the phenomena of heat at a descriptive level, in the elementary school.

Design

This is an exploratory study. It does not attempt to establish causal relationships, but rather seeks to establish a "logical fit" between the factors of cultural knowledge, prevailing scientific paradigms, and environmental factors in such a way that when juxtaposed they provide inferential data (see Hammond-Tooke, 1981).

The general design of this study involves:

1. Establishing whether metaphorical conceptions are present in the selected subjects.
2. Establishing what conceptions (scientific and alternative) the subjects use when explaining tasks involving phenomena associated with heat.
3. Discussing these data in the contexts of the subjects' intellectual and physical environment.

Subjects.

A heterogeneous group of subjects was involved in this study. The selection of subjects was limited by the fact that the interviewers were English speaking and as the subjects spoke a variety of languages, English had to be the language used. This limitation meant that children younger than 13 years were excluded as were rural, unschooled subjects. Both of these groups do not have adequate English to allow testing using interviews.

The subjects were mainly a Sotho group in which the Setswana and North Sotho languages were most common. All the subjects lived on the interior plateau of Southern Africa.

The subjects (total n=20) were schoolchildren (n=10, average age=15 years) and adult workers (n=10, average age=34 years). Of

these adult workers, some were un-schooled workers with little or no schooling (n=4) and the others were factory or office workers with about eight years of schooling (n=6). The schoolchildren had either eight or nine years of schooling, but none had been taught the formal kinetic view of heat. The total sample included males (n=6) and females (n=14).

Data Collection.

Two different types of interview were carried out, namely Interviews-About-Instances and Piagetian clinical interviews. Pilot interviews were carried out to ensure that the techniques used were consistently employed. All interviews were recorded on tape and subsequently transcribed.

1. Metaphorical heat conceptions. The technique used to ascertain whether subjects used metaphorical heat conceptions for various life experiences is described by Osborne and Gilbert (1980) as Interviews-About-Instances. This technique is a semi-structured interview in which the subjects could agree or disagree that people in given life situations could be described as 'hot'. Each situation or instance was portrayed by means of a photograph together with a verbal description of what was happening in the photograph. The subject was asked "Would you say that such a person is 'hot'?" and then "Why would you say that?".

2. Physical heat conceptions. Five tasks involving physical phenomena caused by heat were demonstrated to individuals who were then asked to give their ideas concerning heat, using a clinical interview (see Piaget, 1929; Pines, 1977). These tasks replicated those used by Erickson (1975) and involved the phenomena of boiling water; the conduction of heat along equal rods made of different materials; the expansion of a solid (ball and ring experiment); the expansion of a liquid; the expansion of a gas. In each task the heat source was a methylated spirits burner.

Data Analysis.

The transcripts were analysed using techniques developed by Erickson (1975; 1979) and Hewson (1982). The analysis took the following steps:

1. Formation of the Conceptual Profile Inventory (CPI). The Conceptual Profile Inventory (CPI) was compiled for all subjects. The conceptions were extracted from the verbatim transcripts, categorized into groups, and arranged as a profile reflecting the conceptions utilized by the subjects as a whole. Verbatim examples from the transcripts are given to substantiate each conception. The number of subjects who expressed each conception is given and these data were used to represent the CPI in graphic from. The CPI includes both the metaphorical and physical heat conceptions. Both the authors analysed the transcripts and worked on a basis that consensus was essential. Later on, five independent judges were asked to assess two separate

transcripts to obtain an interjudge reliability score.

2. Representation of knowledge in individual subjects. The transcripts of four subjects were selected in such a way that all the categories in the CPI were represented. Conceptual networks were used to illustrate each of the subjects' conceptions, as well as the early and contemporary scientific conceptions of heat, which were obtained from textbooks.

3. Analysis of dimensions of knowledge. The data obtained in the CPI for the group as a whole and the four selected representative subjects were analysed according to certain dimensions suggested by White (1979). These were: The accord of subject knowledge with both contemporary and early scientific views; the extent and variety of the group's knowledge; the precision of the subject's knowledge; the internal consistency of individual subject's responses; and the shape of the networks of the four representative subjects.

Results

The Conceptual Profile Inventory (CPI).

The full description of the conceptual categories identified in the subjects is given in the CPI, together with exemplars. These are cross-referenced with the subject's code name and the page number of the transcript. See Table 1.

Table 1 About Here

The frequencies of responses on the whole CPI are represented in Figure 3, and the frequencies of responses on the metaphorical heat conceptions sub-categories are represented in Figure 4.

Figures 3 and 4 About Here

The general results from these data show that:

1. Metaphorical heat conceptions are present in 16 of the 20 subjects. This tends to confirm that these conceptions are present, albeit in varying amounts, in people who are semi-urban, somewhat acculturated to Western life and thought, and who are fluent in English as a second language.

2. The physical heat conceptions show a surprisingly high number (12) of people who subscribed to the scientific category of prekinetic/kinetic conceptions (CPI:2.6), and three subjects subscribed to conceptions involving particle arrangement (CPI:2.4).

Alternative conceptions such as those involving models based on observable physical phenomena (CPI:2.1); 'particles split/multiply and recombine' (CPI:2.2); 'particles expand and contract' (CPI:2.3) were found, in 17, 7, and 8 subjects respectively. The figures indicate that these conceptions were expressed frequently. The alternative conception that 'heat is a caloric' (CPI:2.5) had the lowest occurence, i.e., it was only subscribed to by two of the total of 20 subjects.

Interjudge Reliability.

The analyses of the 5 independent judges on two transcripts were compared with the original analyses. Agreement between the judges analyses and the original analyses was 97.5% for the metaphorical heat conceptions and 82.1% for the physical heat conceptions. This was accepted as satisfactory.

Representation of Knowledge Structures.

The structure of knowledge concerning heat has been represented in the form of conceptual networks in which the concepts and the relationships between them are shown (Stewart 1979, Hewson, 1982).

The conceptual networks represent the contemporary scientific view of kinetic heat (Figure 5), and the early scientific view of caloric heat (Figure 6). Figures 7,8,9, and 10 show the conceptual networks of the selected subjects whose conceptions cover the range of ideas expressed in the CPI.

Figures 5,6,7,8,9,10 About Here

The arrangement of conceptions in each network is the same. Each conception appears in a rectangle. It is coded with a CPI number, and includes quotations from original transcripts. The connections between the conceptions are labelled. The subjects' definitions of heat are in a circle, as are the metaphorical heat conceptions.

Discussion

The data are discussed in terms of six of the dimensions suggested by White (1979).

Accord with contemporary scientific view

Although there is a relatively high frequency of responses described as prekinetic or kinetic (CPI:2.6), it should be emphasised that these are somewhat crude, intuitive conceptions. This category involved not only subjects with 9 or 10 years schooling , but also an unschooled domestic worker who said: "Fire is the power to make water boil" (DomW/C), and a factory worker with only 5 years of schooling who defined heat as "heat is almost like a fire, it has got a power" (Eth/D). Many of the subjects who gave responses in the CPI:2.1 category also used metaphorical heat conceptions (i.e. 66% of the sample whose responses fell into this category). The exemplars in the CPI:2.6 show clearly the kinetic predisposition of these subjects.

Accord with early scientific views

Very few of the subjects, in fact only two, gave responses that could be described as caloric (CPI:2.5). These results suggest a divergence from those reported in Western environments. Albert (1978), Erickson (1975; 1979; 1980), Tiberghien (1980), Shayer and Wylam (1981) all report finding evidence of caloric thinking in schoolchildren.

Shayer and Wylam (1981) report that about 80% of their subjects in level 3 who were between 10 and 13 years used a caloric model.* This difference suggests that cultural knowledge (including linguistic factors) and environment may indeed produce cognitive differences.

Extent and variety

The range of conceptions was shown in the CPI and illustrated in the conceptual networks. This shows that alternative conceptions concerning models based on burning/boiling/melting phenomena are popular (CPI:2.1). Alternative conceptions involving particles splitting/multiplying and expanding are also reasonably common (CPI:2.2, 2.3). These latter conceptions do not appear to have been identified by other researchers, except for Erickson (1975) whose category called 'Children's Viewpoints' seems to incorporate some of these alternative conceptions. Albert (1978) and Shayer and Wylam (1981) comment that their students used empirical observations of burning, boiling, and melting to explain heat at a concrete level.

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* Note: While the research methodology in this study followed closely that suggested by Piaget (1929), and replicated some of Erickson's (1975) experiments, the results are not statistically comparable with those of other independent Western researchers. As these studies and ours are qualitative in style, the inferences drawn remain tentative.

Shayer and Wylam (1981) do not consider that their students used these ideas as models, but this does appear to be the case for the subjects in this study where many of them used empirical ideas at a macro level to model explanations at a micro level (CPI:2.1).

Precision

The conceptions expressed in this study were on the whole crude and intuitive. Caramazza, McCloskey, and Green (1981) use the term 'naive' which would be applicable to many of these conceptions, both scientific and alternative.

Internal consistency

Some subjects (for example, unschooled domestic workers) consistently used the burning/boiling/melting model (CPI: 2.1). Others changed their explanatory conceptions according to the task, for example, Eth/D used prekinetic (CPI:2.6) conceptions for all the tasks except the expansion of air task where he suddenly made use of a caloric conception of heat (CPI:2.5).

Shape of the network

The conceptual networks used in this study are easily comparable, as a template shape was used. It is of interest that certain subjects attempted to include a number of conceptions as explanations and were

unable to see that this was either redundant or contradictory. For example see Mma/B (Figure 8) who included both the prekinetic/kinetic conceptions and the particles split/multiply conceptions. Subject Wm/B (Figure 7) is an example of those who connected the particles expand concept with the particle arrangement and prekinetic/kinetic conceptions. These connections are more a case of included ideas than related ideas.

Summary of Results

The data indicate that the subjects in this study used a variety of alternative conceptions to explain heat. They also frequently used prekinetic or kinetic conceptions of heat, and rarely used caloric conceptions.

These results can be viewed in the context of the subjects' cultural beliefs concerning heat and their physical environment. The results concerning the metaphorical heat concepts substantiated the anthropological literature and showed that a particular heat metaphor was prevalent which may be seen as based on experiences of living in a hot, arid part of the country. According to the metaphor, the condition of being hot is thought to be bad (i.e. unhappy, sad, sorrowful, tired, etc.) and involves a conception of agitated blood. While no direct causality can be attributed to this fact, it would appear that there is an inferential "logical fit" between the metaphor

and the high frequency response for prekinetic conceptions.

Further research, using a more quantitative research design involving both Western and Sotho peoples, to establish whether a causal relationship between these factors does exist, could be useful.

Further consideration should be taken of linguistic factors. Harris (1981) suggests that the use of caloric conceptions by Westerners is a semantic problem in which Western languages such as English use words for heat which convey the wrong idea because of their historical antecedents, thereby influencing students to think calorically. Since the subjects used in this study are all African with English as a second language, it is possible to surmise that these results show little evidence of caloric conceptions because the Sotho languages do not have words for heat which are suggestive of the old caloric notions. Indeed the data suggest that the connotative meanings of the word 'heat' for the Westerner and the African are different in some respects. Further research in this area would be appropriate. (See Sutton, 1980 and Isa and Maskill, 1982 for interesting papers in this area).

This study has identified conceptions involving both physical and metaphorical heat in a group of African (Sotho) subjects. It has attempted to understand their conceptions of physical heat in the context of their intellectual environment (i.e. cultural beliefs

involving the heat metaphor) and physical environment. The possible origin of the heat metaphor in the experience of the hot, arid country in which the Sotho peoples live was discussed, and an inferential link between the two was suggested.

The observed physical conceptions of heat in this sample were discussed in the context of the early and contemporary paradigms in Western science, namely caloric and kinetic theories of heat. It was noted that this sample frequently expressed naive conceptions which could be described as prekinetic, and caloric conceptions were uncommon. This finding appears to conflict with the fact that many adolescent students in the West give caloric views of heat in similar interviews. Inferential conclusions are that Western languages may have a predisposition towards a meaning of heat which has caloric connotations, and that this predisposition is lacking in Sotho languages. On the other hand, the Sotho languages appear to involve connotative meanings of heat which are influenced in some way by the presence of a powerful heat metaphor in the Sotho cultural beliefs. This metaphor, which involves the conception of 'hot' being a personal condition concerning 'agitated blood', fits logically with the prekinetic views expressed by many Sotho subjects.

Implications for Education

The results of this exploratory study indicate that people belonging to the Sotho group in southern Africa may be at a relative

advantage in learning about heat energy when compared with their Western counterparts. This may be because their existing knowledge concerning heat is, in some sense, close to a kinetic view, and this could well be due to the influence of a prevalent cultural metaphor involving conceptions of heat. The research shows that most Sotho students do not have to unlearn outdated scientific notions of caloric heat, which are deeply rooted in Western thinking, before being able to acquire the contemporary kinetic view of heat. This is because features of their particular existing knowledge may be more easily reconciled with modern, formal scientific theories in specific subject areas, such as that discussed in this paper.

It is likely that the Sotho students who did subscribe to the caloric view probably acquired these ideas in school as a consequence of learning in the medium of English. This hypothesis would be worth researching further. In addition, further research into the generalizability of the results in this study is indicated. More qualitative and quantitative analyses of the causal effect of external aspects of a functioning cognitive system (e.g., the role of cultural metaphor) on concept formation promises to be a fruitful area for further research.

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TABLE 1. CONCEPT PROFILE INVENTORY FOR HEAT

Subjects are Black schoolchildren, unschooled domestic workers, and semi-schooled factory/office workers. The number of subjects who subscribe to each category is given. Each exemplar is cross-referenced with the subject's code name and the transcript page on which the quotation occurs. (N=20).

CPI CATEGORY	EXEMPLARS
1. METAPHOR HEAT	
1.1 Travel (10): Persons who are tired/exhausted from travelling long distances are described as hot.	"The travellers have got a heat because they have been travelling for quite a long time... He's not allowed to see a baby... He must go outside and wash his feet... (to cool) he can take ash from the stove and rub it on his hand... and the little baby's fingers and legs." DomW/A p.1. "In my language I would say that these people are hot because they have been travelling and because they are tired." Mma/D p.12.
1.2 Waiting (4): Persons who become impatient or restless from waiting a long time are described as hot.	" When they are hot you can see that they are restless." Mma/D p.13. "She is hot...(if she is waiting for a long time)". NIPR/A p.3.
1.3 Childbirth/Pregnant/Menstruation (11): Women who have recently given birth or who are pregnant or who are menstruating are described as hot.	"Yes... when the baby is born they (visitors) are supposed not to come in where she is because... the mother is still hot..." NIPR/B p.1. (When the woman is pregnant) "Naturally her blood is hot." NIPR/B p.1.
1.4 Anger (12): An angry person is hot, his blood is hot.	"In Tswana you can say (the angry man) is o bollo - he is boiling -- he is hot with fury." Wm/A p.2. "Yes (the angry man) is hot. I can say he's hot because he's angry. If the person is getting angry he feel hot all over his body." Eth/D p.4.

1.5 Sickness/Pain (8) :

Many forms of sickness involving pain cause a person to be hot - not to be confused with fever.

"They (sick boys) are hot because they have got pains in them and maybe they are hot pains...I would say it is the same (as these other pictures)."
Mma/A p.15.

1.6 Bereavement/Grief/Sorrow (13) :

Death of a person causes immediate family to be hot due to feelings of grief and sorrow. Similarly, persons who attend a funeral are hot.

"Because everything is ... like a burning flame and once she (the widow) is getting pain... everything is just sad... so everything is hot."
Mma/C p.3.

"Yes I will say she (the widow) is hot because she'll be sorrow of the husband."
Mma/K p.3.

1.7 Lightning (6):

Persons killed by lightning are said to be hot and must be buried in appropriately cool places.

"Yes it is (bad for a person to be killed by lightning. In Tswana you are not allowed to touch that person for some time because... he has that warmth of lightning in him."
Mma/B p.11.

1.8 Initiation (9) :

Boys involved in initiation ceremonies at puberty are described as hot.

"Yes, he's (the initiate) hot because some boys they don't like to go there, they are forced by their parents to go there."
NIPR/A p.3.

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2. PHYSICAL HEAT

2.1 Conceptions based on observable physical phenomena (17) :

Everyday experiences involving burning, boiling, melting, hot air rising, etc. are used to explain heat at the micro level.

"Yes, the heat is the smoke that is coming in the hot water..."
NIPR:A p.6 (Suggestion that steam is the smoke of burning water).

"So, the heat burns more quickly in the aluminium rod because it is lighter."
NIPR:A p.7 (Analogy with experience that less dense wood burns more quickly than wood that is very dense).

2.2 Particles solit/multiply and recombine (7) :

Heated particles increase in number by splitting or multiplying so that there are more particles of the same substance (occupying more space).

"...(You get more molecules) because of this heat, because as it is burning it gets more hotter, so the molecules...the amount o them is increasing."
Mma/C p.8.

2.3 Particles expand/contract (8) :
Individual particles increase in size when heated apparently involving concepts of growth.

"Oh... I am going to summarise about heat... When we heat steel and water, the molecules get bigger..."
Mma/E p.12.

2.4 Particle arrangement (3) :
The packing or binding of particles influences the extent to which heat is transmitted in an object.

"Heat would travel faster in a light material because... (the particles are not so close)... when (the material) is much heavier (the particles) are more packed."
Wm/B p.5.

2.5 Caloric conceptions (2) :
Heat is viewed as a fluid having certain properties of matter.

"This heat it comes (into the ball).. (the heat) is full of something... and when it gets here its going to make the thing more of its size... and when it cools, (the heat) goes back with all its constituents and then (the ball) returns to its size."
Mma/A p.11.

2.4 Prekinetic and kinetic conceptions (12) :
Heat is viewed as energy which involves particle movement.

"When they (the particles) become heated the particles bombard each other and break and release... energy."
Wm/B p.4.

"I think heat makes the molecules that are in (the material)... to move faster... and when they are moving fast they are causing more pressure because they bump against each other."
Mma/D p.6.

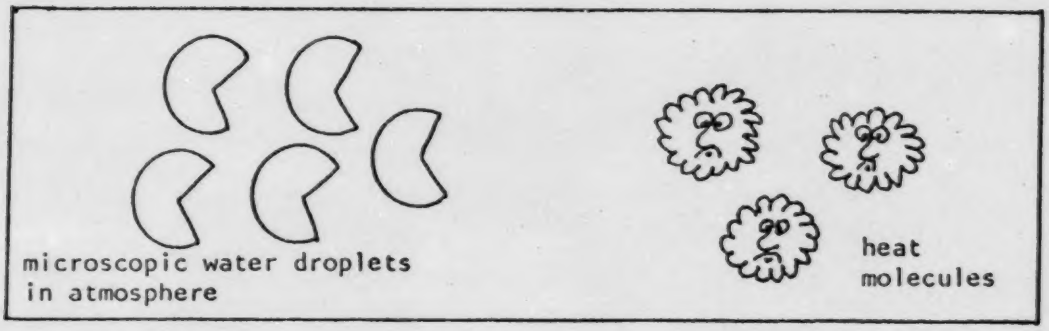

Figure 1. Extract from an advertisement in 'The Star' (1982)

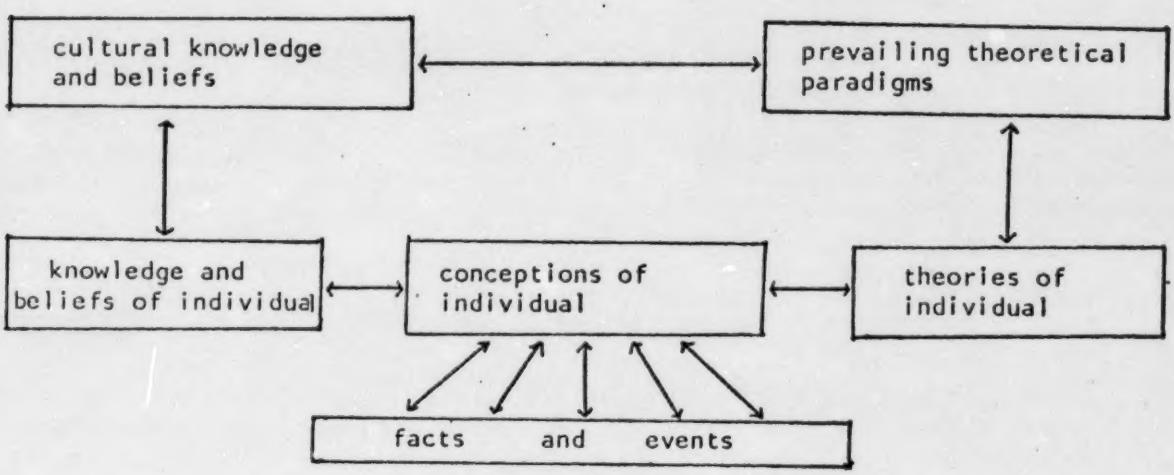

Figure 2. Diagram showing the dynamic interaction between conceptions and the cultural knowledge, prevailing paradigms and physical facts and events (After Petrie, 1976).

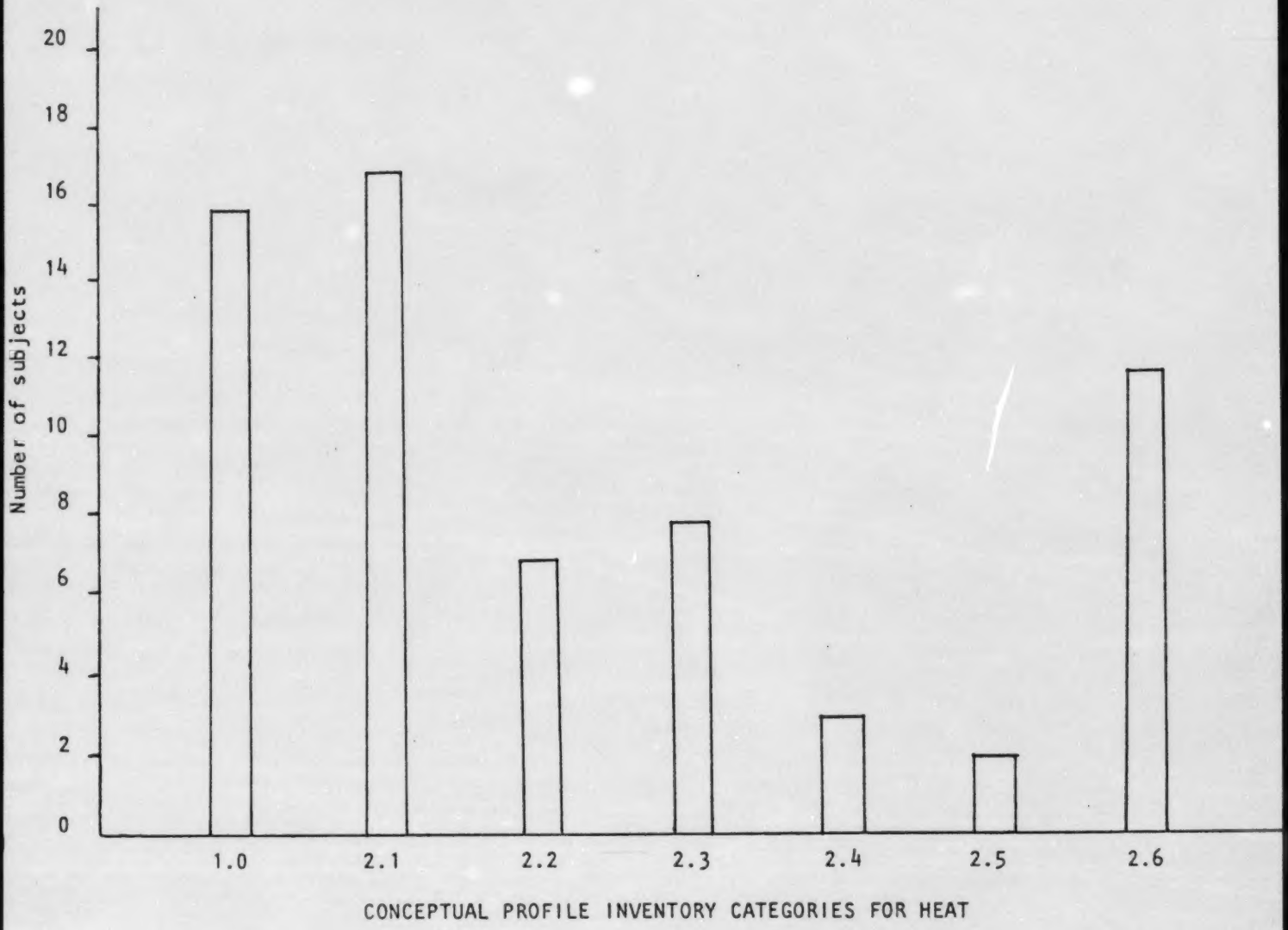

Figure 3. Graph showing the number of subjects who subscribe to subcategories in both metaphorical and physical heat categories of the CPI.

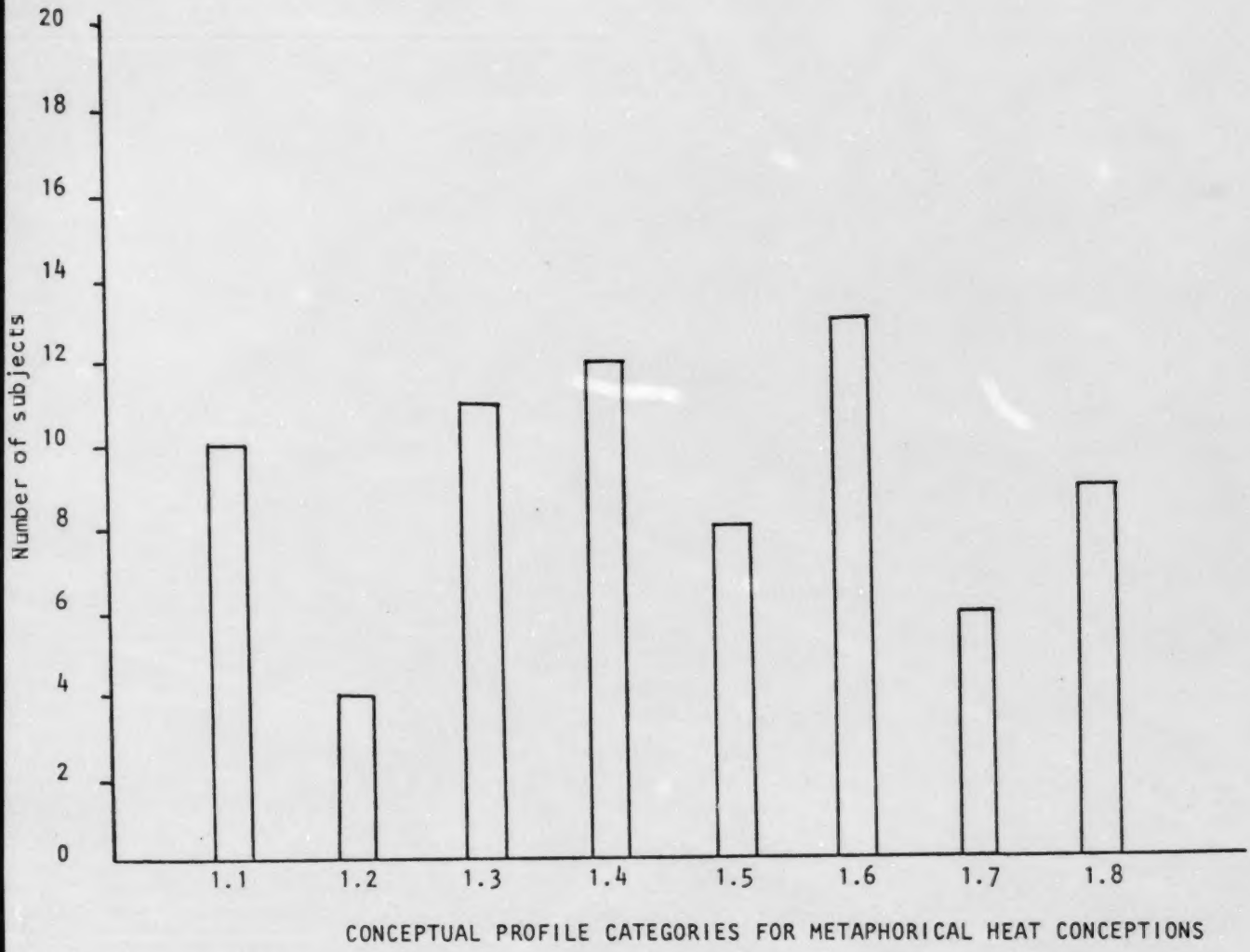

Figure 4. Graph showing the number of subjects who subscribed to subcategories in the metaphorical heat category of the CPI.

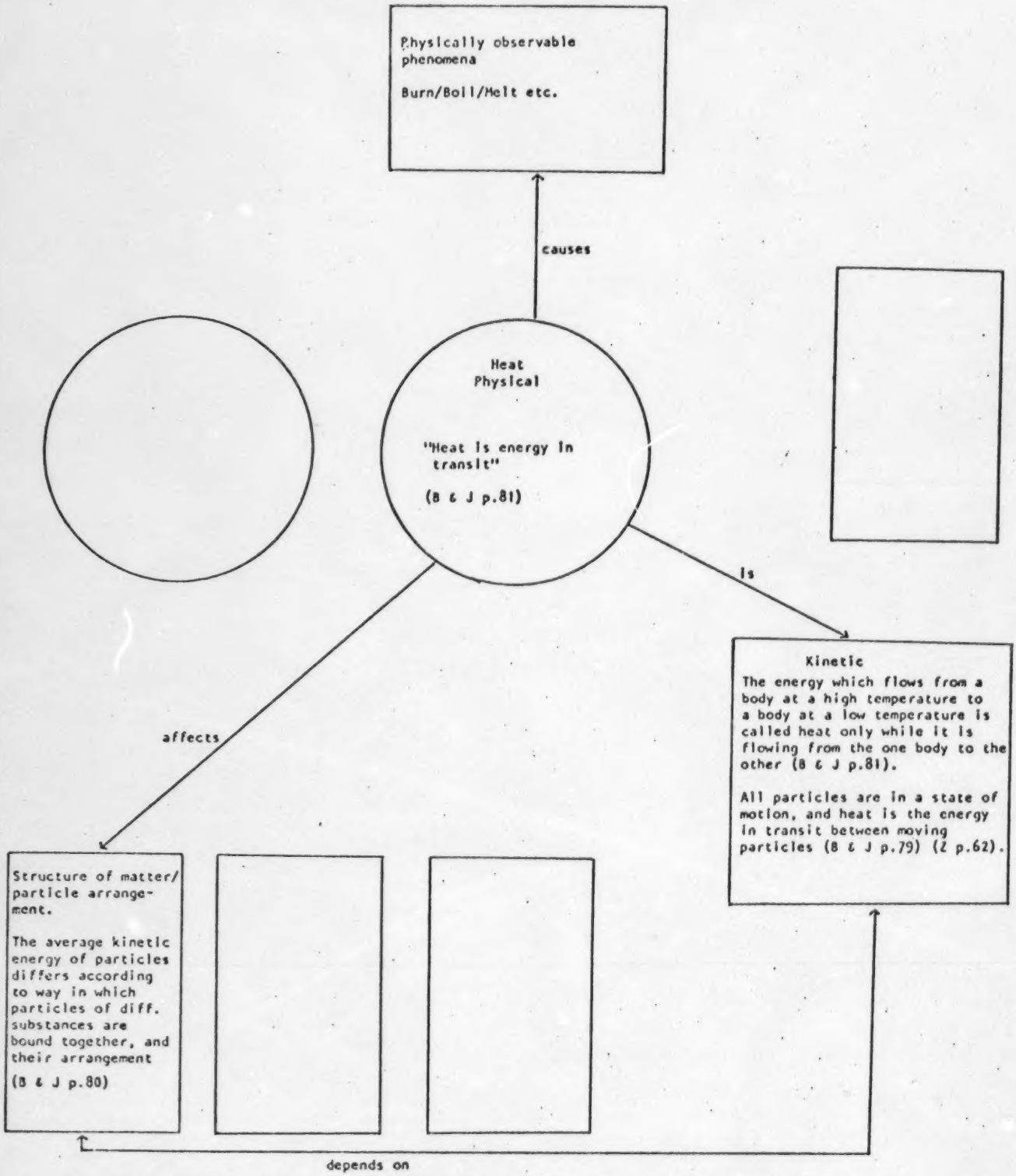
Physically observable phenomena
Burn/Boil/Melt etc.
causes
Heat
Physical
"Heat is energy in transit"
(B & J p.81)
is
affects
Kinetic
The energy which flows from a body at a high temperature to a body at a low temperature is called heat only while it is flowing from the one body to the other (B & J p.81).
All particles are in a state of motion, and heat is the energy in transit between moving particles (B & J p.79) (Z p.62).
Structure of matter/ particle arrangement.
The average kinetic energy of particles differs according to way in which particles of diff. substances are bound together, and their arrangement
(B & J p.80)
depends on

Figure 5. Contemporary scientific paradigm of heat as kinetic energy according to selected school textbooks. (Brink and Jones, 1977; Zemansky, 1957).

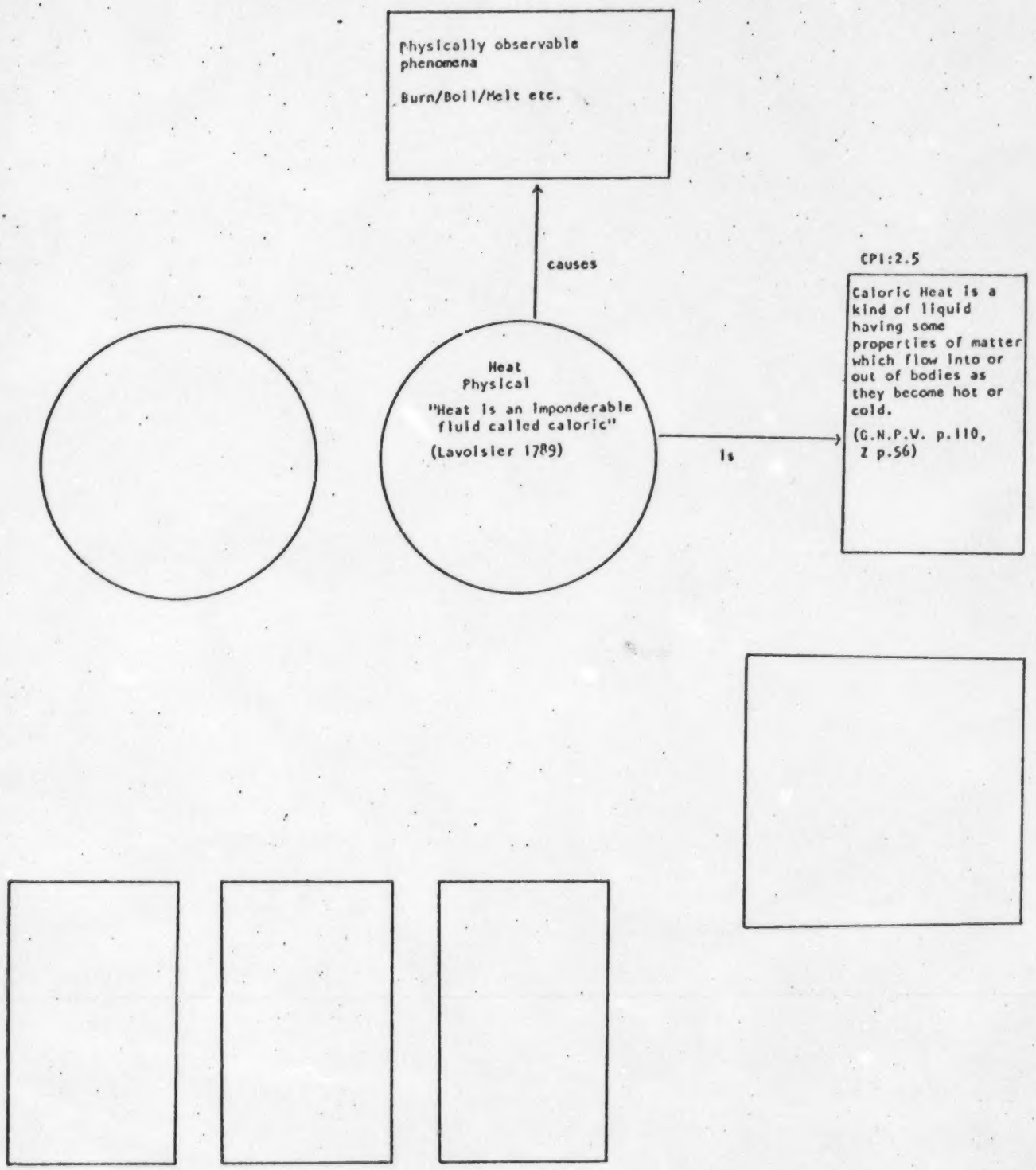
Physically observable phenomena
Burn/Boil/Melt etc.
causes
CPI:2.5
Caloric Heat is a kind of liquid having some properties of matter which flow into or out of bodies as they become hot or cold.
(G.N.P.V. p.110, Z p.56)
Heat
Physical
"Heat is an imponderable fluid called caloric"
(Lavoisier 1789)
is

Figure 6. Early scientific paradigm of heat as caloric, according to selected textbooks. (Lavoisier, 1789; Gordon, Neser, Pienaar and Walters, 1970; Zemansky, 1957).

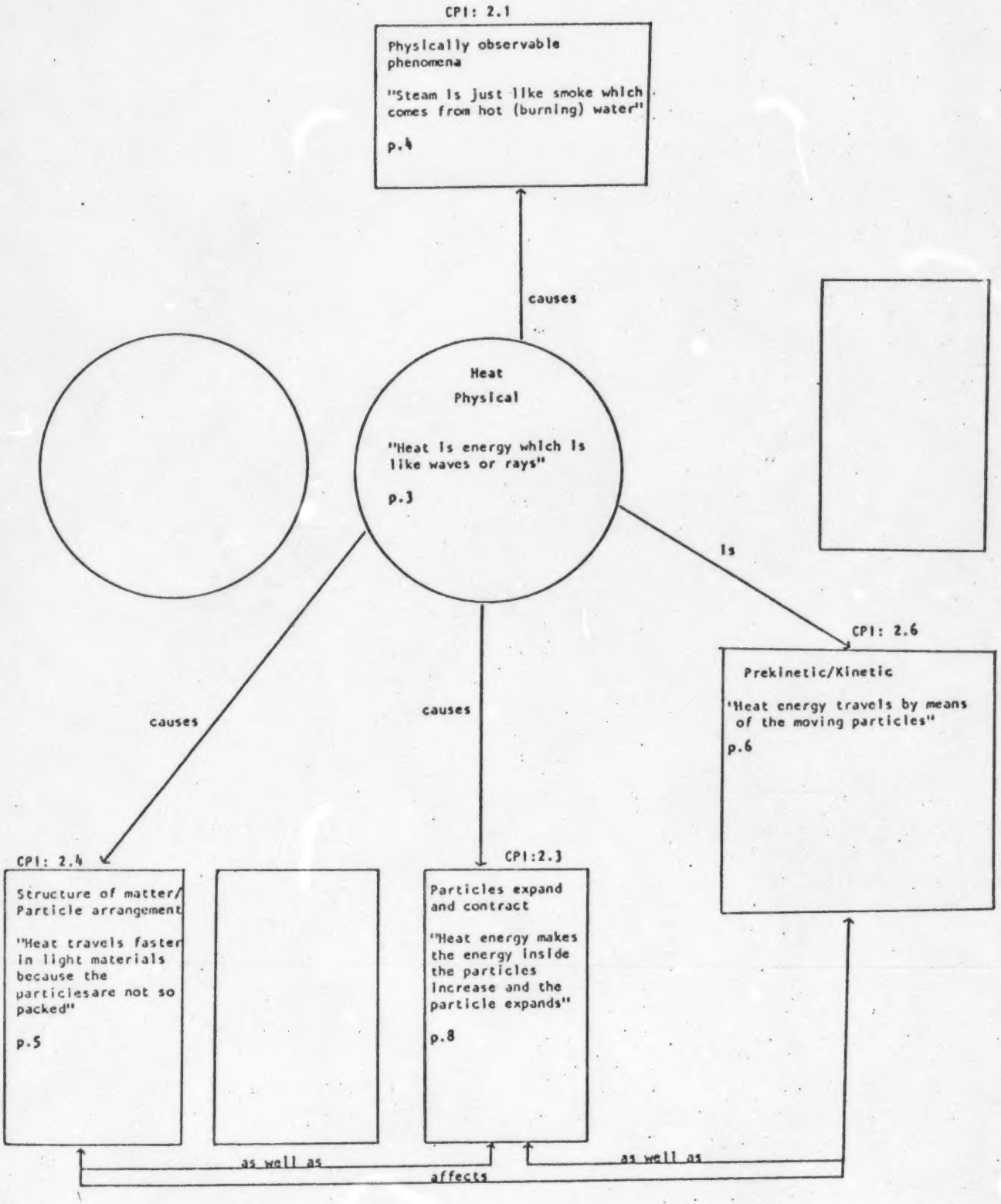

Figure 7. Subject: Wm/B

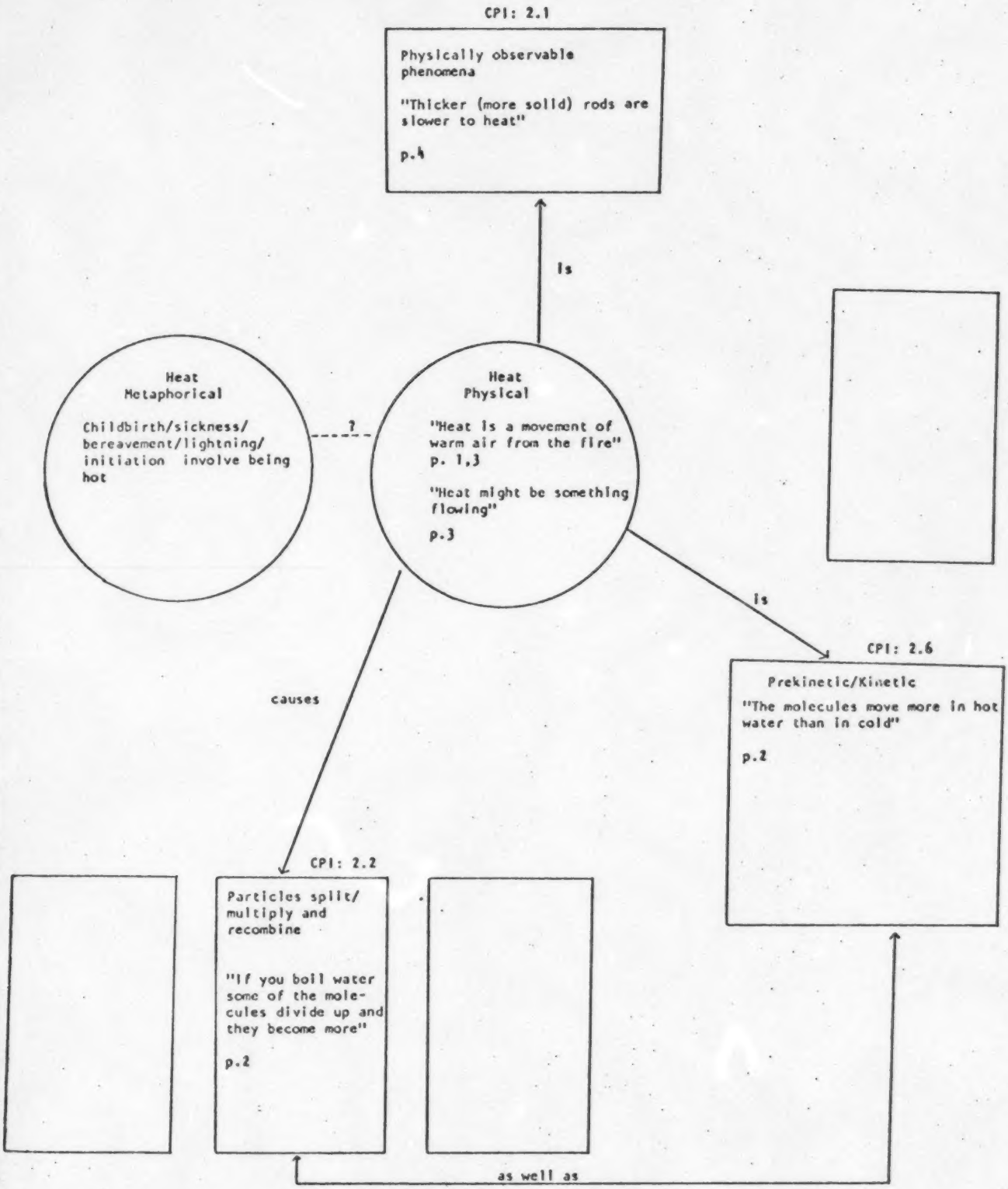

Figure 8. Subject: Hma/B

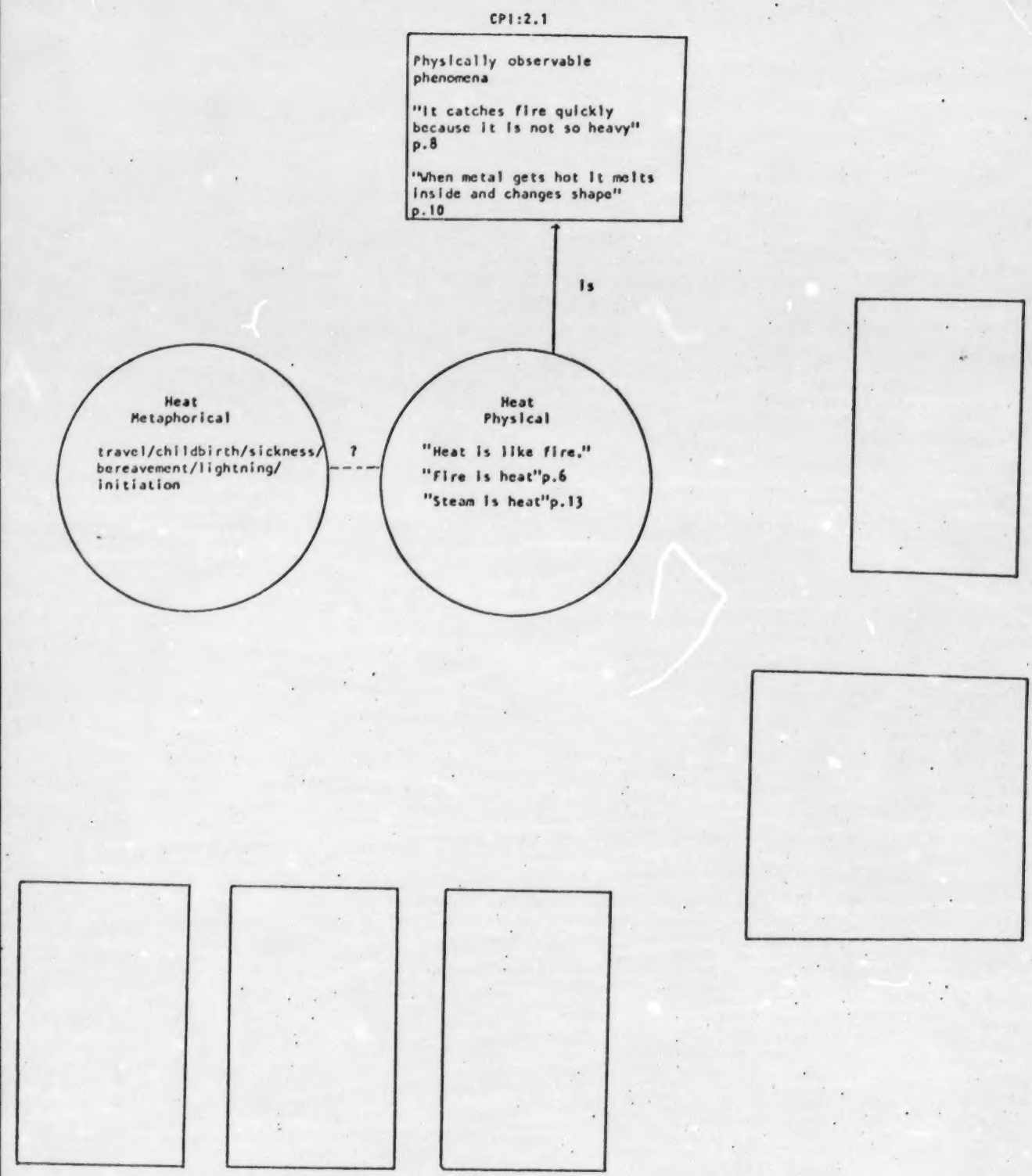

Figure 9. Subject DomV/A

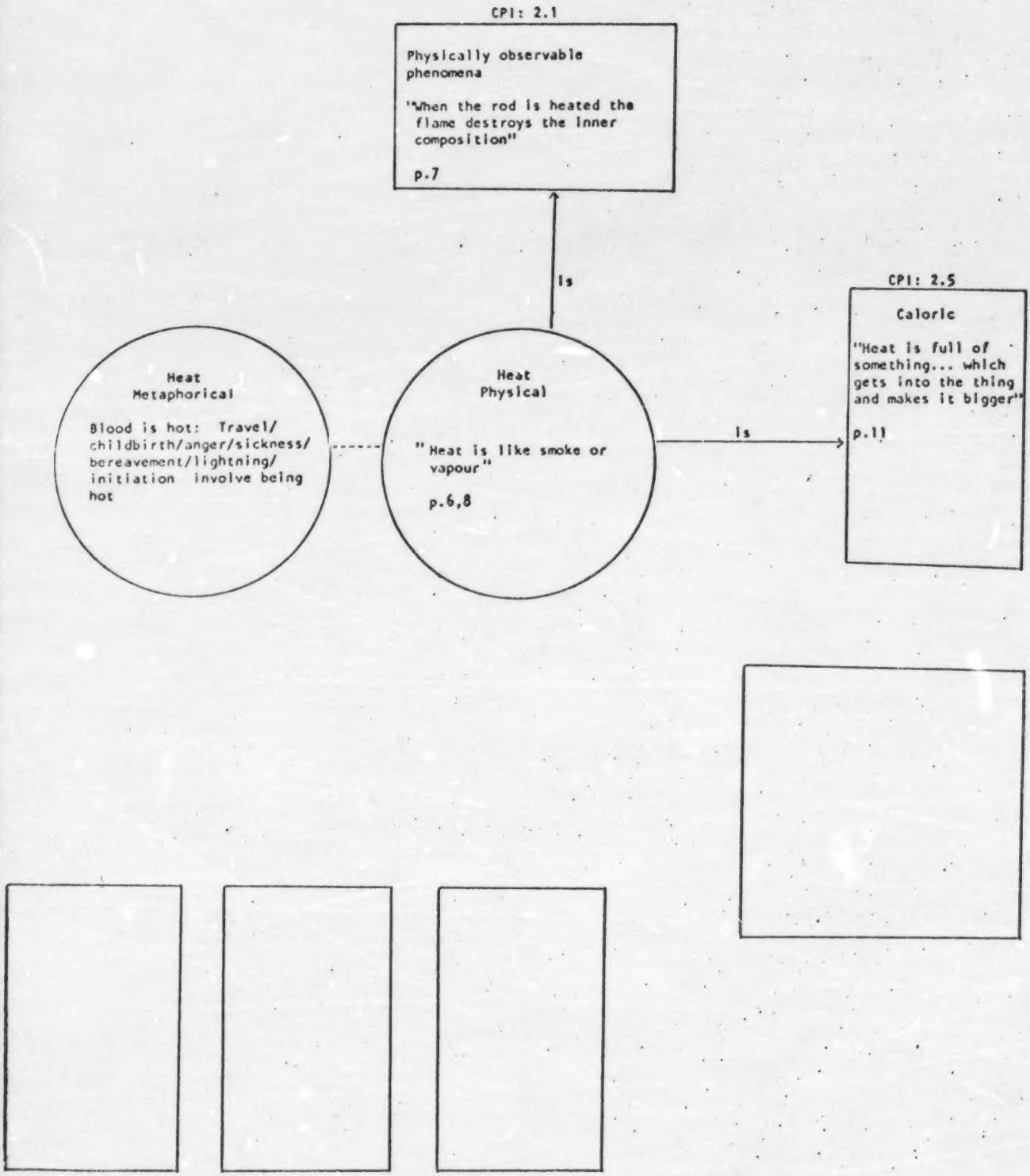

Figure 10. Subject: Hma/A